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ABSTRACT

This paper explores the concept of educational psychology as a "linking science" between (1) theory and research in psychology and learning and (2) the educational arena of the schools. A linking science is defined as a special structure that intervenes between scientific theory and practical application. The author's first major point is that a linking science is needed between psychology and education, but that traditional approaches of applying theory to practice are wrong. To substantiate her opinion, the author reviews the work of three experimental psychologists, A. W. Melton, K. W. Spence, and B. J. Underwood. Among their concerns is that classroom settings and individual differences confound the straightforward application of theories derived in controlled laboratory situations. The author's second major point is that researchers must be aware of the curriculum design problems for which their research will ultimately be applied. This will ensure useful relevance between the two fields, psychology and education, and will promote the success of educational psychology as a linking science. The paper concludes with a discussion of important areas for research that will assist the development of the linking science. (AV)

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Educational Psychology: Linking Science to Design

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Educational Psychology: Linking Science to Design

In this paper, I explore the various ways instructional designers can use knowledge from psychology in their design work. The major variables in my formulation will be how the domain of design problems are defined, what form of psychological knowledge it is that is being used, and how that knowledge is used. What I hope to demonstrate is that there are alternative methods for linking the psychology knowledge base to the process of design. In so doing, I hope to clarify the nature of educational psychology considered as a linking science. A major point I want to achieve is to separate the issues of whether a linking science is necessary from what such a linking science would be like.

The Concept of a Linking Science

The concept of a linking science, a special structure that intervenes between scientific theory and practical application, was first envisioned by Dewey and was the topic of a recent paper by Glaser (1976). Dewey proposed that in the same way engineering lies between physics and the practical workingmen in the mills and scientific medicine lies between natural science and the physician that there would need to be a linking science between psychological theory and practical work. Glaser's (1976) candidate for the linking science is a body of knowledge he referred to as a psychology of instruction defined in turn (p. 3) as a "linking science" between the scientific knowledge of learning (including human cognition and development) and educational applications.

To propose that a linking science is needed carries with it several implications. An important implication is that without such a linking science, the ties from the discipline of learning psychology to educational practice will be unsystematic. That is, although one might intend to build a given application making full use of information from theory and research, the best of intentions are still subject to considerable variability of implementation. I would like to explore some commentaries on what is involved in "applying" science and thereby point out some sources of variability of implementation.

How the Application of Science Takes Place: Spence, Underwood, and Melton

In a very interesting symposium published in the Harvard Educational Review (1959), three experimental psychologists were asked to answer the question, "Can the laws of learning be applied in the classroom?" I review their replies here because I think collectively they raised some of the classical issues that one must be mindful of in any attempt to "apply" scientific knowledge. It will be my subsequent point that a linking science, properly understood, can function to minimize many of the difficulties inherent in "application."

Develop basic theory. Kenneth Spence's answer to the question, "Can the laws of learning be applied in the classroom?" was that first, we do not know enough about the laws of learning to provide a theoretical foundation that would be adequate for the formulation of principles to guide application. Spence noted that the job of

the "pure" psychologist is to discover those precise quantitative laws that will provide the basis for a comprehensive theory of learning which would in turn serve as the basis for principles of application. The applied psychologist is limited in his attempts at theory building because, as Spence puts it, the findings of applied research are usually highly specific to the particular situation being investigated with the result that a new research study must be made for each new situation. Thus, Spence felt we shall not have an applied psychology of any power or generality until adequate basic theory was built. The learning environment in real world situations is very complex and heterogeneous and the determining variables too numerous. Such complexity is currently an obstacle to achieving generality inherent in comprehensive theory. I believe it would not be too far off the track of Spence's essay to ascribe to him the position that the problems of instructional practice are best addressed by advancements in basic theory where such theory is built by the pure psychologist.¹ The research strategy would be to work from the study of simple situations to the study of complex ones.

A key source of variability in the application of psychology to the classroom is pointed up in Spence's remarks. This is in the

¹It is, of course, the case that the development of selected basic theories also contributes strongly to the development of a linking science. Thus, it is not inimical to the concept of a linking science to say that the further advancement of basic theory is an important goal for a linking science or, in Glaser's terms, a psychology of instruction.

diversity of theoretical frameworks within which "pure" psychologists work and its consequence for definition of the psychology knowledge base that is to be "applied." As many of us know, Spence's idea of theory was in the form of precise quantitative laws relating measures of hypothetical constructs that have cause and effect relationships to each other. For some instructional questions this type of theory is appropriate; for others, it is not, because it does not make contact with the instructional variables that actually or potentially can control a given learning event. In her discussion of the relevance of semantic features for vocabulary development, Block (1978) stated that it was not relevant for the important instructional questions. As Greeno (1976) has noted regarding learning theories prior to 1965, the content of psychological theories to that point in time had been quite thin for educational/instructional questions. In opposition to Spence, Atkinson (1973) argues that an all-inclusive theory is not a prerequisite for the development of optimal instructional procedures. What is needed instead, as he suggests, is a model that captures the " . . . essential features of that part of the learning process being tapped by an instructional task. . . ." However, without further specification of what the essential features are and how to go about identifying them, we are still left with considerable diversity of basic theory. Based on these considerations it is obvious that a variable in the application of psychology to the classroom is the adequacy of the basic theory selected for guiding the particular instructional application. A linking science could

minimize this variability by introducing a criterion of instructional relevance as a mechanism to aid the selection among basic theories.

Spence goes on to point out that the obstacle present in applying the laws of learning we currently have is that we have no way of knowing whether things work the same way in the applied situation as in the laboratory. This is because we have not developed enough basic theory to determine the range of ways things can work. Then, too, when we have tried to figure out the way things work by studying them au naturel we have not arrived at reliable generalizations.

The matter of whether things work the same way in the laboratory and in the classroom is an issue that, to my knowledge at least, has received little in the way of explicit conceptual analysis from classroom process and teacher behavior researchers. One exception to this is Rothkopf's (Note 1) work in which he explicitly wishes to develop his theory of instruction in a way consistent with findings of laboratory research. A concern about whether things work the same way can take many forms; I would think it means conscious attention to developments in instructionally relevant theory and consideration of one's findings in the context of current theories. I do not mean simply rationalizing why certain events are selected for a functional analysis. Applied findings need to be understood in terms of basic theory, and I believe there is far too little attention given to explicitly tying (via analytical argument) applied findings to an instructionally relevant basic theory.

There will be gaps in information and assumptions that have to be made; these will provide the basis for further instructional experiments. One function of a linking science, therefore, could be to foster the development of understanding of the management of learning in the context of the science of learning and to identify the informational requirements of instructional design decisions as problems to be studied in further basic research.

Generalization, Classroom Variables, and Field Studies

In response to the question, "Can the laws of learning be applied to the classroom?," Benton Underwood suggests that at first hand, the question might seem to be one of judicious consideration of the possibilities of scientific generalization. That is, one could assess the similarity of the conditions between the laboratory and the classroom and then make a judgment as to whether or not the principles in the laboratory would hold in the classroom. Underwood continues to point out the fatal flaw in this particular strategy of "using psychological principles in design," namely,

as in all forms of human endeavor, there are clear individual differences among psychologists in the zest for such extrapolation. (p. 107)

In order to bridge the gap between the laboratory and the classroom, Underwood suggests that in deciding whether or not to generalize laboratory findings, one ought to be mindful of certain potential constraining factors such as the similarity and representativeness of laboratory tasks compared to those of the school curriculum,

whether or not there are basic differences between the laboratory subject and the student in the classroom, and whether or not the laboratory subject leaves critical parts of himself outside the laboratory. Thus, Underwood poses for us a set of potential conditions upon our "principles" of learning. The notion is that whether or not the principles can appropriately be applied is dependent upon contextual variables such as the type of student population, type of learning task with which one is dealing, and the "learning strategy" adopted by the student. Thus, Underwood rejects context-free generalizations and advises in its place, context-sensitive generalizations. A linking science, it would seem to me, must be concerned with not only with what knowledge is being linked (the issue I attribute to Spence) but also how it is being linked, i.e., the logic of the link (the issue I attribute to Underwood).

Underwood further suggests another way the relationship between the laboratory and real-life situations might be evaluated, removing some of the dangers involved when a scientist over-extends facts and theories. If one looks to laboratory research for variables that exert powerful, in contrast to weaker, influences over learning, then presumably these would be the variables whose influences would be felt in the more complex real world setting. Once they are identified, field studies should be conducted to confirm the influence of such variables. Underwood's suggested list of potential controlling variables very much bespeak his verbal learning background: meaningfulness, intratask similarity, etc. As unimportant variables, Underwood suggested affective characteristics

of the material, massed versus distributed practice, etc. We can recast Underwood's suggestion here as a suggestion that we need to see if the principles "hold up" in the real world setting. This, of course, has been the manner of synthesizing research in educational psychology (McKeachie, 1974). The function of a linking science would be to keep better track of the conditions under which the principles are valid. We could also recast Underwood's suggestion in the form of a general proposition about how to go about identifying variables that make a difference. What would be worth evaluating is the general proposition that powerful variables in simpler settings are useful guides to variables that control learning in more complex settings. Whether or not this is true is an open question, but one consequence of the matter is that the magnitude of effects is the design-relevant quantity to measure (see also, Suppes, 1973). Within a design framework, this issue becomes one of given all the instructional variables we must specify in the design of materials, which ones should be given the most effort and attention in actual materials construction or in quality review of materials? Size of effects have implications for resource allocation; in the view of design presented subsequently (the optimization view) resource allocation is fundamental to the design problems. One function of a linking science would be to suggest new ways to organize information from basic research.

How science and technology should relate. Perhaps the most perceptive reply to the question, "Can the laws of learning be applied to the classroom,?" was offered by Arthur Melton. Melton

replied that it was the wrong question. What is of concern, Melton stated, is the nature of the relationship between the science of learning and the technology of education. Melton's discussion of the proper nature of the relationship lays the conceptual groundwork for other functions of a linking science. An important consequence of Melton's remarks as they suggest functions of a linking science is to demonstrate how the most predominant definition of educational psychology is inadequate.

As an educational psychologist, I have always been irked by the definition of educational psychology as the "systematic application of the theories and findings of psychological science research to educational practice." There are two important operational consequences of such a definition. The first is that when the design process starts with what we know from psychology (where such knowledge is in the form of theoretical or empirical principles or the results of specific experiments) and works forward (i.e., transforms such knowledge into prescriptions for instruction which specify the conditions of instruction), the result is that we have constrained the domain of instructional design problems we can consider in a particular way. First, depending upon the variables that are related via the principle, it may or may not be possible to implement the principle in practice. As Gagné (1971) notes "there is often no way to manipulate the training situation in the manner suggested by the principle." One function of a linking science would be to insure ecologically valid learning research.

The second consequence of an "application" point of view is that problems of design become to be viewed in a particular way. The design problem becomes one of specifying values of learning or instructional variables in a manner consistent with the results of research (this can also be called a conditions of learning view of design). An "application" approach to design entails a particular definition of design; a definition that defines design as the specification of values of instructional variables within a taxonomy of tasks (see Merrill and Boutwell, 1973). The reasoning goes that

if achievement is enhanced under one value of a variable, relative to another, it is the first that should be implemented in design. Nowhere is this particular view of instructional design more apparent than in the Courseware development model organized by David Merrill and his colleagues (see, e.g., Reigeluth, Merrill, and Bunderson, 1978). Although the Merrill model assumes the traditional definition of instructional design, there are considerable strengths to it in relation to context-free generalization as a method of linking the knowledge base to design. First, there is an explicit accounting of contextual variables. Each prescription contains domain specifications (see Reigeluth et al., 1978). Second, prescriptions are organized by a taxonomy of performance objectives and prescriptions emerge from principles that apply to types. This is in contrast to principles that emerge from a body of knowledge referred to as "verbal learning research" for example. The Merrill model also provides for the minimization of individual differences among designers in implementation of the principles for adjunct aids to design, Handbooks for Instruction have been developed. Finally, research to generate the basic knowledge base (more principles) is driven by instructional considerations (i.e., it is instructionally relevant).

It is interesting to note, however, that within the body of his paper Melton pointed out that education is not just the straightforward application of the science of learning, any more than engineering is just a straightforward application of the physical science (p. 98). Developments via the Merrill model, the work of

Susan Markle and others show considerable advances over a simple, context-free method of generalizing from the laboratory to the classroom. Even in the most traditional mold for educational psychology, one in which we define it to be application of the principles, we have gone some distance in bridging the gap from laboratory to practice.

Melton makes several other points about the relationship between the science of learning and the management of learning processes that help me to clarify what I mean when I say the current predominant definition of educational psychology as technology defined in the sense of principle-application is inadequate (or better yet, I might say incomplete). I believe Melton implies a different definition, or at least an expanded definition, of educational technology. He clearly did not believe technology is equivalent to the "application" of the science of learning, choosing instead to define technology as the "successful management of learning processes." There are two important implications of this recast definition. The first is that design has its own questions and the domain of design problems we define for study ought not to be constrained by the classical view of educational technology as the application of principles from learning research (that is, the classical view of design embodied in the work of taxonomic design theorists such as Merrill and Gagné). Rather, what we must admit is that study of the management of learning is a problem area in its own right and management questions ought not to be constrained to a collection of task variable specification questions. The

consequence of this is that the design task environment is the proper place to start in formulating design problems. This should be done prior to and independently of establishing what the relevant psychology information requirements are. Simon (1975) would argue that the design problem would need to be formulated in a manner responsive to the logic of optimization. The important point regarding ways of working to help build a linking science is that the classical model of linking — from principles to prescriptions for application — is only one model for a design science. It can be clearly contrasted to a model where the design problem is formulated first, in the context of a relevant theoretical framework and defined in a manner responsive to the logic of optimization. Thus, what I am suggesting is that instructional technology can be defined in a non-traditional way, one that views it to be the development of optimal management policies. One function of a linking science would be to recognize alternative versions of it.

Besides differences in the theoretical framework that importantly shapes how design problems are defined, there are differences in the goals for a technology defined as application versus a technology viewed more in terms of the logic of optimization. The goals of the two approaches to design are quite different. Taxonomic approaches aim for the development of prescriptive propositions that guide specification of task conditions out of a taxonomy of instructional variables (Reigeluth et al., 1978). Optimization/decision approaches aim for the development of an optimal policy. Differences in goals, of course, dictate different evaluation strategies.

Another point made by Melton that is critical for the purposes of my paper is his point (p. 100) that the science of learning can provide guidance for the management of learning . . . if . . . and I want to emphasize the if . . . one has understanding of the science, understanding of the learning to be managed, and ingenuity. There are two corollary points embedded here: the first is that interrelating the science of learning with questions of the management of learning is an intelligent process, not, as Melton puts it, " . . . a cookbook translation of empirical law into management principle. . . " Anyone familiar with the Handbooks for designing instruction produced by Courseware (Freedman and Hughes, 1978) might think they smack of "recipes" for instruction. It is the case that although the Merrill model considerably strengthens the process of application, not all of its features might be considered positive. It is, however, after all, only one version of a linking science. Certainly, however, in contrast to Handbooks which proceduralize design, there are more "intelligent" modes within which scientists might advise designers.² One mode that I have participated in involves telling what I know about the cognitive psychology of instruction in a given subject area and reacting to prototype tasks designed to be consistent with these ideas by high level instructional designers. This mode assumes design is "intelligent," both conceptually and data-driven.

²I am grateful to James Greeno for this point.

A second corollary of Melton's statement about the three requirements for successful linking is that individuals involved in linking scientific knowledge to instructional practice must have understanding of the learning to be managed, i.e., an understanding of learning and performance of the actual tasks to be instructed and the nature of the curriculum within which they are embedded. This point underscores the importance of experiences, for individuals who are to become "linkers," that incorporate design and study of actual curricular products. The function of a linking science in this regard is to legitimize certain educational experiences for educational psychology students.

To summarize, I have been discussing the response of three experimental psychologists to the question, "Can the laws of learning be applied to the classroom?" The question is a central one for educational psychology, a field whose emergence was predicated on the assumption that the scientist has something to say to the technologist. The answers from the three psychologists were distinctly different. Spence said we need development of basic theory before we can solve problems of application. Underwood treated the question as a matter of cautious generalization supported by functional analyses and field studies in the actual classroom setting. Neither Spence nor Underwood considered the nature of problems that arise in applied settings. Melton stated it was the wrong question and his discussion gave me the opportunity to broaden the definition of educational technology and expand upon the concept of a mutually supporting relationship between science

and technology. As I have noted, the classical format for dissemination of psychological knowledge to practitioners was thought to be a set of "principles" that could be "applied." Hopefully, I have at least hinted at the advances we have made over early crude versions of applying knowledge of this sort, and I have explicitly described a second approach to educational design, the optimization approach as an alternative to "application."

An interesting question to consider is how our three experimental psychologists would have reacted to the idea of a "linking science." They would be in an excellent position to assess the idea, having just thought about linking science to practice without an explicit intermediary structure. Although I, of course, could not predict with certainty how each individual would respond, I will review some of my earlier remarks to show how a linking science can at least in part counteract some of the reservations about extending science to practice expressed by these psychologists; then, I will make a few state of the art comments.

The Functions of a Linking Science

I shall assume that the idea of a linking science will influence how scientists and technologists conduct their work. It should influence how they define their problems and it should promote specific attention to what their problem implies for the science and the technology. And, in particular, the logic of linking ought to be explicitly worked out.

Instructional Relevance

One important function of a linking science is to make explicit and operational what is involved in the designation

"instructionally relevant" psychological theory. In a linking science one form of psychological theory is not just as good as another; some are more relevant for instructional purposes than others. Spence's emphasis on theory development as the way to solve applied problems led us to examine the question of what kind of theory. It is likely that following the attitude Spence portrayed, he would react to this proposed function of a linking science by saying we currently have no way of defining what we mean by the phrase, criterion of instructional relevance. If so, he would, of course, put his thumb on a major developing concern within instructional psychology.

Except for a systems definition of problems in instructional development (analyses of competence, description of initial state, etc., Glaser, 1976) recast into an information processing framework, we have little more in the way of more definitive guidelines for what constitutes instructionally relevant basic psychological research. This criterion will, I think, become better articulated when we become able to more sharply define curriculum design problems and when we become more systematic and explicit about defining the requirements upon theory imposed by problems in technology.

In a linking science, the criterion of instructional relevance places explicit constraints on theory development and actively shapes its direction. Thus, in addition to the standard criteria for the evaluation of theories — parsimony, heuristic power, generality, etc. — another is added. Thus, a linking science helps us to be reliable about translating theory to practice.

Personal theoretical preferences of the learning psychologist ought not to enter strongly into a designation of the knowledge that is relevant to instruction. This has implications certainly for the hiring of psychological consultants and the selection of psychological theories to be taught in educational psychological courses.

What is Linked and How it is Linked

Underwood's concern for judicious generalization leads one to focus upon various models whereby generalizing is done. One function of a linking science would be to promote attention to the reasoning employed when a design problem is solved using information from psychology. The logic involved in linking ought to be explicit.

In fact, it is important to be explicit about three components of a linking science: the content and form of discipline knowledge being used, the development of a clear statement of the design problem being addressed, and making the logic used to work forward or backward from one domain to the other explicit. The weakest model of linking occurs when a principle is plucked from learning psychology with little regard for important contextual variables, "applied" via a strategy of label matching and potentially resulting in a recommendation for a program variable that has already been implemented, or that cannot be implemented because there is no way the program variable can be implemented. Ways to strengthen the linking procedure include: (1) explicitly designating important contextual variables; (2) using a taxonomy of learning tasks; (3) using job aids in development work to remove troublesome sources

of individual differences; and (4) validating each prescription developed. These latter qualities are associated with the work of David Merrill and Susan Markle. One cannot help but think that Underwood would prefer the explicit structuring of a linking science to unexamined generalizations from laboratory research.

Expanding the Definition of Design

Melton's conception of the relationship between science and technology has actually laid a conceptual foundation for the linking science. One important consequence of Melton's remarks for educational psychology considered as a linking science is the contrast between the traditional view of it and a more recent view in terms of optimization. Educational psychology more generally and instructional technology more specifically can thereby be defined in several ways depending upon frameworks used by the designer.

A fundamental problem for instructional technology is the establishment of a taxonomy of approaches to instructional design in such a way that one approach constrains, in a useful way, the development of another and in such a way that the structure of the linking science is apparent. In other writings (Block, Note 2; Block, 1979), I have struggled with the concept of what such a taxonomy might be like, or more modestly put, I have tried to describe points of contact between different approaches to design considering such "far out" contrasts as the Merrill model compared to intelligent CAI. I think that we need to look at approaches to design from the point of view of what psychology knowledge base the designer is using, how the designer formulates the design problem, and the logical procedure used in working back and forth

between the knowledge base and the increasingly precise formulation of the design problem. In the end, we should be able to trace, in a step-by-step manner, how design decisions were made with the input knowledge base. One thing various approaches to instructional design must do is to specify how the designer works within each of them when undertaking a design task.

How Much is Science and How Much is Art

Any discussion of a linking science must attend to the issue of whether design is largely science or whether design is largely art. To postulate that a linking science is needed assumes that quality design is partly at least analytical, i.e., it is not wholly intuitive nor is it properly considered raw empirical in nature.

(I use these terms in the sense used by Reigeluth et al., 1978).

A critical issue in the structure of a linking science is what problems of design can be solved in an automated fashion and what problems will require higher level cognition of the designer to a considerable degree.

To state that design is, in part at least, analytical does not, however, presuppose the analytical framework within which it is to be done. There has been a tendency among psychologists to assume that because an approach to design claims to be "systematic" that it leaves no room for Melton's ingenuity or Gage's "clinical judgment." This is not the case. In fact, it is possible to identify, among the individuals working within classical taxonomic approaches, considerable diversity with respect to the role played by the judgment of the designer or teacher. In the Merrill model,

it is indeed the case that the ingenuity of the individual designer is chopped up into little pieces and reduced to steps in a procedure (see Reigeluth et al., 1978). Design is proceduralized so much so that a technician can produce the instructional materials. Susan Markle, on the other hand, prefers to train designers by presenting the three broad principles of programmed instruction, then elaborating their application by showing "intelligent" versus unintelligent (i.e., stupid) implementations of the principles in instructional frames. One approach to design appears "cook-booky;" the second explicitly recognizes the principles serve only as guidelines with the ingenuity of the designer playing a major role if they are to be intelligently implemented.

In summary, I hope that by discussing some of the qualities of a linking science, I have added some clarification to that murky phrase, "the mutually supportive relationships between the science of psychology on the one hand and instructional practice on the other."

Needed Work to Advance the Development of the Linking Science

Classical taxonomic approaches to design, based on the idea that design is the systematic application of principles from laboratory research, have long dominated educational technology and instructional design. This approach to design has seen considerably rapid, recent development in the work of David Merrill and his colleagues and in the emergence of Courseware, Inc. The consequences for the development of a design science has been that we have tended to view instructional design problems in terms of

their analogies in laboratory research and the result has been continued addition of prescriptive propositions in association with cells of the taxonomy of tasks. Taxonomic approaches presuppose a particular view of instructional design; what I think we presently need to do is extricate ourselves from the definition of technology taxonomic approaches suppose and formulate alternative ways to think about issues of instructional design.

One way that I have found to be productive for identifying issues in the management of learning and the technology of design is to study current instructional practices in the school subject areas. This can be done by scrutinizing instructional methods texts used in college methods courses, examining actual curricular materials, and reading descriptions of how curriculum design is done by designers when they are being careful to report their logic and to be analytical in their descriptions.

I would like to propose two areas of investigation that will contribute to a better definition of curriculum design questions. These include (1) the conduct of careful analyses, in the context of an appropriate theoretical framework, of instructional strategy questions raised by curriculum specialists, teachers, and other practitioners or that are implied by the actual curricular materials and (2) the study of conditions of learning implemented by a school curriculum, as a problem in decision making and optimization. Investigations such as these are a form of instructional quality review in the manner of Markle (1975), although I am proposing the use of other frameworks in addition to the framework of instructional principles. And, the purpose of work of this type is less

to admonish curriculum developers for failure to employ the principles in their design (which only Markle can do so well) and more to identify the curriculum issues within contemporary frameworks for research. Work by Resnick and Beck (1975) and Frase and Fisher (Note 3) has preceded me in applying an information process framework to the analysis and recommended improvements of instructional materials.

A useful framework for the comparative analysis of instructional strategies, one which makes contact with the instructional strategy issues curriculum technologists have defined is the framework of information processing psychology. Recognizing the important contributions of information processing psychology, Glaser and Resnick (1972), in an Annual Review of Psychology chapter, described how developments in basic theory could assist development of the knowledge base relevant to instruction. Subsequently, the influence of information processing psychology has resulted in considerable advances in our understanding of knowledge-based performance in a variety of school tasks: composition, geometry problem solving, and others (see Glaser, Pellegrino, and Lesgold, 1978). Other developments in cognitive psychology, particularly work in intelligent computer-assisted instruction (see, for example, Collins, Warnock, and Passafiume, 1975; Burton and Brown, 1978) contribute new analyses of instructional content that define it in terms of structures of knowledge to be taught and "intelligent" processes of instruction, that work to build knowledge of content in the student and that are deeply adaptive. Collectively considered,

these developments in an information processing psychology relevant to instruction supply a framework for the comparative analysis of instructional strategies.

In addition to developments in cognitive psychology relevant to instruction, Richard Atkinson's important work on the application of decision theory to the instruction-learning process is another seminal development for educational psychologists. Atkinson has explicitly shown how decision theory and the logic of optimization can be applied to instructional design decisions, pointing to the importance of particular technical frameworks, such as applied decision analysis, which comprise a significant part of the formalisms associated with the "design sciences" (see Simon, 1975). While developments in information processing psychology allow deeper understanding of instructional processes, the decision theoretic approach to instructional design allows better ways to formalize the structure of curriculum design questions. Both developments strengthen, in a very significant way, the theoretical framework within which problems and questions related to the design and analysis of instruction can be posed. Both developments imply that the curriculum for training educational psychologists ought to include some sampling of disciplines other than psychology that are relevant to the design sciences (e.g., computer science to strengthen knowledge of information processing and management science to develop knowledge of various decision making models).

In other writings (see Block, 1978; Block, Note 4), I have specifically illustrated how particular questions of reading curriculum

design can be interpreted within an information processing framework and an optimization framework. Numerous interesting curriculum design questions exist and could serve as the substantive focus of curriculum research activity with the curriculum implemented by computer-assisted instruction for better control of the instructional situation. But, you say, hasn't educational psychology always been concerned with design questions, questions such as "Does the use of pictures help or hinder reading comprehension?" This is true; but such questions are drawn up out of the context of the more comprehensive curriculum design problem, they are not responsive to the design decisions as the designer sees them, and the way they have been formulated fails to capture the multi-dimensional nature of design. Curriculum design in reading and in other disciplines has many elements of an operations research problem. It is an attempt to maximize multiple outcomes while minimizing related potential costs, and the program variables you manipulate are interdependent, to various degrees. The interdependence can be viewed in terms of a minimax procedure. For example, if you minimize visual confusability in the design of a grapheme sequence, you may restrict the meaningfulness of the words that can be generated for the children to read (minimizing confusability maximizes comprehension interference from less meaningful words).

To summarize, in this paper, I have delineated variously structured linking sciences contrasting, most fundamentally, traditional taxonomic approaches that work on an "application"

definition of technology to more recent optimization approaches which provide a framework for defining design questions that arise in the process of designing a curriculum. There are two main messages of my paper. First, the concept of a linking science currently has several examples that can be compared in terms of three components: (1) the psychology knowledge base, (2) the domain of design problems defined, and (3) the logic that interrelates the two. We need to sharpen our understanding of these approaches to design in order that they may be compared, because, according to my colleague Guy Groen (1978, p. 62), "It is not through dogma but by the clash of rival research programs that science flourishes."

The second main message of my paper is that one important way to assist the development of educational psychology as a design science is to achieve better definition of curriculum design questions. We need to achieve such definition in an ecologically valid manner; we need to conduct research on these questions; and we need to examine their implications for the psychology knowledge base, in turn. I realize that others before me have had similar theses and I mark Melton and Glaser chief among them. What I hope to have accomplished in this paper is to separate the issue of whether a linking science is needed (yes, it is) from what kind of linking science we ought to have (we don't know yet but one thing for sure is that we need to adopt a contrastive framework for the evaluation of the various linking structures that exist). Then, I described what I see to be important areas for research that will assist the development of the linking science.

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